Ghosts in Resonance chiral theory

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- χPT and Resonance chiral theory
- Propagators of spin one particles
- One loop renormalization
- Conclusion

χPT Lagrangian

[Gasser, Leutwyler 1984]

$$\mathcal{L}_\chi = \mathcal{L}_\chi^{(2)} + \mathcal{L}_\chi^{(4)} + \mathcal{L}_\chi^{(6)} + \dots$$

with LO term

$$\mathcal{L}_\chi^{(2)} = \frac{F_0^2}{4} \langle u_\mu u^\mu + \chi_+ \rangle$$

and NLO Lagrangian

$$\begin{aligned}
\mathcal{L}_\chi^{(4)} =& L_1 \langle u_\mu u^\mu \rangle^2 + L_2 \langle u_\mu u^\nu \rangle \langle u^\mu u_\nu \rangle + L_3 \langle u_\mu u^\mu u_\nu u^\nu \rangle + L_4 \langle u_\mu u^\mu \rangle \langle \chi_+ \rangle \\
&+ L_5 \langle u_\mu u^\mu \chi_+ \rangle + L_6 \langle \chi_+ \rangle^2 + L_7 \langle \chi_- \rangle^2 + L_8/2 \langle \chi_-^2 + \chi_+^2 \rangle \\
&- i L_9 \langle f_+^{\mu\nu} u_\mu u_\nu \rangle + L_{10}/4 \langle f_{+\mu\nu} f_+^{\mu\nu} - f_{-\mu\nu} f_-^{\mu\nu} \rangle \\
&+ i L_{11} \langle \chi_- (D_\mu u^\mu + i/2 \chi_-) \rangle - L_{12} \langle (D_\mu u^\mu + i/2 \chi_-)^2 \rangle \\
&+ H_1/2 \langle f_{+\mu\nu} f_+^{\mu\nu} + f_{-\mu\nu} f_-^{\mu\nu} \rangle + H_2/4 \langle \chi_+^2 - \chi_-^2 \rangle
\end{aligned}$$

NNLO contains more than 90 terms [Bijnens, Colangelo, Ecker 1999]

Saturation of LEC

χPT Lagrangian contains free parameters that can be saturated by resonances

Theory for effective description of resonances $\rightarrow$ Resonance chiral theory

In large N_C limit one can write the Lagrangian in the separate form

$$\mathcal{L}_R = \mathcal{L}_{GB}^{(2)} + \mathcal{L}_{GB}^{(4)} + \mathcal{L}_{GB}^{(6)} + \mathcal{L}_{res}^{(4)} + \mathcal{L}_{res}^{(6)}$$

Integrating out the resonances

$$\int \mathcal{D}R \exp\left(i\int d^4x\, \mathcal{L}_{res}\right) = \exp\left(i\int d^4x\, \mathcal{L}_{\chi,res}\right)$$

we restore the χPT Lagrangian

$$\mathcal{L}_\chi = \mathcal{L}_{GB} + \mathcal{L}_{\chi,res}$$

Estimation of LECs:

$O(p^4)$: [Ecker, Gasser, Pich, de Rafael, 1989]

$O(p^6)$: [Cirigliano, Ecker, Eidemuller, Kaiser, Pich & Portoles 2006], [Kampf, Moussallam 2006]

Vector resonances

Restriction to vector resonances 1^{--}
They transform nonlinearly under $U(3)_R \times U(3)_L$

$$R \rightarrow hRh^\dagger$$

where

$$R = \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{6}}\omega_8 + \frac{1}{\sqrt{3}}\omega_0 & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{6}}\omega_8 + \frac{1}{\sqrt{3}}\omega_0 & K^{*0} \\ K^{*-} & \overline{K}^{*0} & -\frac{2}{\sqrt{6}}\omega_8 + \frac{1}{\sqrt{3}}\omega_0 \end{pmatrix}$$

Three possible descriptions:

$\rightarrow \mathcal{L}_V$ with Proca fields V_μ

$\rightarrow \mathcal{L}_R$ with antisymmetric tensor fields $R_{\mu\nu}$

$\rightarrow \mathcal{L}_{RV}$, Lagrangian in first order formalism (both fields)

[Kampf, Novotný, Trnka, 2006]

Problems with equivalence

Proca $\not\leftrightarrow$ tensor, unless some contact terms are added by hand (generally infinite tower)

$$\mathcal{L}_R^{(\leq 6)} = \mathcal{L}_R^{(4)} + \mathcal{L}_R^{(6)} \rightarrow \mathcal{L}_{V,eff} = \sum_{n=3}^{\infty} \mathcal{L}_{V,eff}^{(2n)},$$

$$\mathcal{L}_V^{(\leq 6)} = \mathcal{L}_V^{(6)} \rightarrow \mathcal{L}_{R,eff} = \sum_{n=2}^{\infty} \mathcal{L}_{V,eff}^{(2n)},$$

First order formalism

- it is more general, it contains more interaction terms
- all structures in effective chiral Lagrangian as in Proca and tensor, no additional contact terms
- never "worse" than Proca or tensor
- no doubling of degrees of freedom at tree level

Proca field Lagrangian

$$\mathcal{L}_V = -\frac{1}{4}\langle \hat{V}^{\mu\nu}\hat{V}_{\mu\nu}\rangle + \frac{1}{2}M^2\langle V_\mu V^\mu\rangle + \mathcal{L}_{V,int}$$

where $\hat{V}^{\mu\nu} = D^\mu V^\nu - D^\nu V^\mu$ and $\langle\rangle$ are traces over group indices

Integrating out resonances $\rightarrow$ contribution to $\mathcal{O}(p^6)$ LECs

$\Rightarrow V^\mu = \mathcal{O}(p^3)$

LO interaction terms in Proca formalism are of order $\mathcal{O}(p^6)$:

[Prades 1994]

	$\mathcal{O}(p^6)$ even parity	coupling
1	$\mathrm{i}\langle V^\mu[u^\nu, f_{-\mu\nu}]\rangle$	α_V
2	$\langle V^\mu[u_\mu, \chi_-]\rangle$	β_V
3	$\langle \hat{V}^{\mu\nu} f_{+\mu\nu}\rangle$	$-\frac{1}{2\sqrt{2}} f_V$
4	$\mathrm{i}\langle \hat{V}^{\mu\nu}[u_\mu, u_\nu]\rangle$	$-\frac{1}{2\sqrt{2}} g_V$

	$\mathcal{O}(p^6)$ odd parity	coupling
5	$\mathrm{i}\epsilon_{\mu\nu\alpha\beta}\langle V^\mu u^\nu u^\alpha u^\beta\rangle$	θ_V
6	$\epsilon_{\mu\nu\alpha\beta}\langle V^\mu \{u^\nu, f_+^{\alpha\beta}\}\rangle$	h_V

f_V, g_V $\rightarrow$ analagous terms in tensor formalism contribute to $\mathcal{O}(p^4)$ LECs

Antisymmetric tensor formalism

$$\mathcal{L}_R = -\frac{1}{2}\langle D_\alpha R^{\alpha\mu} D^\beta R_{\beta\mu}\rangle + \frac{1}{4}M^2\langle R_{\mu\nu}R^{\mu\nu}\rangle + \mathcal{L}_{R,int}$$

The chiral order of tensor field $R_{\mu\nu} = \mathcal{O}(p^2)$, LO interaction Lagrangian

$$\mathcal{L}^{(4)}_{R,int} = \frac{F_V}{2\sqrt{2}}\langle R^{\mu\nu} f_{+\mu\nu}\rangle + \frac{iG_V}{2\sqrt{2}}\langle R^{\mu\nu}[u_\mu, u_\nu]\rangle$$

Contribution to $\mathcal{O}(p^4)$ LECs

$$L_1' = \frac{G_V^2}{2M^2}, \quad L_2' = \frac{G_V^2}{4M^2}, \quad L_3' = -\frac{3G_V^2}{4M^2}, \quad L_{10}' = -\frac{F_V^2}{4M^2}, \quad H_1' = -\frac{F_V^2}{8M^2}$$

Basis of $\mathcal{O}(p^6)$ interaction terms:

→ incomplete for odd intrinsic parity sector

[Ruiz-Femenia, Pich, Portoles, 2003]

→ complete for even intrinsic parity sector

[Cirigliano, Ecker, Eidemuller, Kaiser, Pich, Portoles, 2006]

Antisymmetric tensor formalism

	$\mathcal{O}(p^6)$ even parity with R	
1	$\mathrm{i}\langle R_{\mu\nu}u^\mu u_\alpha u^\alpha u^\nu\rangle$	λ_1^V
2	$\mathrm{i}\langle R_{\mu\nu}u^\alpha u^\mu u^\nu u_\alpha\rangle$	λ_2^V
3	$\mathrm{i}\langle R_{\mu\nu}\{u^\alpha, u^\mu u_\alpha u^\nu\}\rangle$	λ_3^V
4	$\mathrm{i}\langle R_{\mu\nu}\{u^\mu u^\nu, u^\alpha u_\alpha\}\rangle$	λ_4^V
5	$\mathrm{i}g_{\alpha\beta}\langle R_{\mu\nu}f_-^{\mu\alpha}f_-^{\nu\beta}\rangle$	λ_5^V
6	$\langle R_{\mu\nu}\{f_+^{\mu\nu}, \chi_+\}\rangle$	λ_6^V
7	$\mathrm{i}g_{\alpha\beta}\langle R_{\mu\nu}f_+^{\mu\alpha}f_+^{\nu\beta}\rangle$	λ_7^V
8	$\mathrm{i}\langle R_{\mu\nu}\{\chi_+, u^\mu u^\nu\}\rangle$	λ_8^V
9	$\mathrm{i}\langle R_{\mu\nu}u^\mu\chi_+ u^\nu\rangle$	λ_9^V
10	$\mathrm{i}\langle R_{\mu\nu}[u^\mu, D^\nu\chi_-]\rangle$	λ_{10}^V
11	$\mathrm{i}\langle R_{\mu\nu}\{f_+^{\mu\nu}, u^\alpha u_\alpha\}\rangle$	λ_{11}^V

	$\mathcal{O}(p^6)$ even parity with R	
12	$\langle R_{\mu\nu}u_\alpha f_+^{\mu\nu}u^\alpha\rangle$	λ_{12}^V
13	$\langle R_{\mu\nu}(u^\mu f_+^{\nu\alpha}u_\alpha + u_\alpha f_+^{\nu\alpha}u^\mu)\rangle$	λ_{13}^V
14	$\langle R_{\mu\nu}(u^\mu u_\alpha f_+^{\alpha\nu} + f_+^{\alpha\nu}u_\alpha u^\mu)\rangle$	λ_{14}^V
15	$\langle R_{\mu\nu}(u_\alpha u^\mu f_+^{\alpha\nu} + f_+^{\alpha\nu}u^\mu u_\alpha)\rangle$	λ_{15}^V
16	$\mathrm{i}\langle R_{\mu\nu}[D^\mu f_-^{\nu\alpha}, u_\alpha]\rangle$	λ_{16}^V
17	$\mathrm{i}\langle R_{\mu\nu}[D_\alpha f_-^{\mu\nu}, u^\alpha]\rangle$	λ_{17}^V
18	$\mathrm{i}\langle R_{\mu\nu}[D_\alpha f_-^{\alpha\mu}, u^\nu]\rangle$	λ_{18}^V
19	$\mathrm{i}\langle R_{\mu\nu}[f_-^{\mu\alpha}, h_\alpha^\nu]\rangle$	λ_{19}^V
20	$\langle R_{\mu\nu}[f_-^{\mu\nu}, \chi_-]\rangle$	λ_{20}^V
21	$\mathrm{i}\langle R_{\mu\nu}D_\alpha D^\alpha(u^\mu u^\nu)\rangle$	λ_{21}^V
22	$\langle R_{\mu\nu}D_\alpha D^\alpha f_+^{\mu\nu}\rangle$	λ_{22}^V

	$\mathcal{O}(p^6)$ even parity with RR	coupling
1	$\langle R_{\mu\nu}R^{\mu\nu}u^\alpha u_\alpha\rangle$	λ_1^{VV}
2	$\langle R_{\mu\nu}u^\alpha R^{\mu\nu}u_\alpha\rangle$	λ_2^{VV}
3	$\langle R_{\mu\alpha}R^{\nu\alpha}u^\mu u_\nu\rangle$	λ_3^{VV}
4	$\langle R_{\mu\alpha}R^{\nu\alpha}u^\mu u_\nu\rangle$	λ_4^{VV}
5	$\langle R_{\mu\alpha}(u^\alpha R^{\mu\beta}u_\beta + u_\beta R^{\mu\beta}u^\alpha)\rangle$	λ_5^{VV}
6	$\langle R_{\mu\nu}R^{\mu\nu}\chi_+\rangle$	λ_6^{VV}
7	$\mathrm{i}\,g^{\beta\mu}\langle R_{\mu\alpha}R^{\alpha\nu}f_{+\beta\nu}\rangle$	λ_7^{VV}

Antisymmetric tensor formalism

	$\mathcal{O}(p^6)$ odd parity with R	coupling
1	$\epsilon_{\mu\nu\rho\sigma}\langle R^{\mu\nu}\{f_+^{\rho\alpha}, D_\alpha u^\sigma\}\rangle$	c_1/M
2	$\epsilon_{\mu\kappa\rho\sigma}\langle R^{\mu\nu}\{f_+^{\rho\sigma}, D_\nu u^\kappa\}\rangle$	c_2/M
3	$\mathrm{i}\epsilon_{\mu\nu\rho\sigma}\langle R^{\mu\nu}\{f_+^{\rho\sigma}, \chi_-\}\rangle$	c_3/M
4	$\mathrm{i}\epsilon_{\mu\nu\rho\sigma}\langle R^{\mu\nu}[f_-^{\rho\sigma}, \chi_+]\rangle$	c_4/M
5	$\epsilon_{\mu\nu\rho\sigma}\langle D_\lambda R^{\mu\nu}\{f_+^{\rho\lambda}, u^\sigma\}\rangle$	c_5/M
6	$\epsilon_{\mu\kappa\rho\sigma}\langle D_\nu R^{\mu\nu}\{f_+^{\rho\sigma}, u^\kappa\}\rangle$	c_6/M
7	$\epsilon_{\mu\nu\rho\sigma}\langle D^\sigma R^{\mu\nu}\{f_+^{\rho\lambda}, u_\lambda\}\rangle$	c_7/M

	$\mathcal{O}(p^6)$ odd parity with RR	coupling
1	$\epsilon_{\mu\nu\alpha\sigma}\langle\{R^{\mu\nu}, R^{\alpha\beta}\}D_\beta u^\sigma\rangle$	d_1
2	$\epsilon_{\mu\nu\alpha\beta}\langle\{R^{\mu\nu}, R^{\alpha\beta}\}\chi_-\rangle$	d_2
3	$\epsilon_{\rho\sigma\mu\lambda}\langle\{D_\nu R^{\mu\nu}, R^{\rho\sigma}\}u^\lambda\rangle$	d_3
4	$\epsilon_{\rho\sigma\mu\alpha}\langle\{D^\alpha R^{\mu\nu}, R^{\rho\sigma}\}u_\nu\rangle$	d_4

	$\mathcal{O}(p^6)$ with RRR	coupling
1	$i\langle R_{\mu\nu}R^{\mu\rho}R^{\nu\sigma}\rangle g_{\rho\sigma}$	λ^{VVV}

$\rightarrow$ sufficient for all three-point Green functions up to $\mathcal{O}(p^6)$

$\rightarrow$ study of VVP Green function and high energy constraints

[Ruiz-Femenia, Pich, Portoles, 2003]

First order formalism

$$\mathcal{L}_{RV} = \frac{1}{4}M^2\langle R_{\mu\nu}R^{\mu\nu}\rangle + \frac{1}{2}M^2\langle V_\mu V^\mu\rangle - \frac{1}{2}M\langle R_{\mu\nu}\hat{V}^{\mu\nu}\rangle + \mathcal{L}_{RV,int}$$

The interaction part contains the sum of interaction terms in Proca and tensor formalisms + mixing term

$$\mathcal{L}_{mix}^{(6)} = \frac{1}{2}M\sigma_V\epsilon_{\alpha\beta\mu\nu}\langle\{V^\alpha, R^{\mu\nu}\}u^\beta\rangle$$

Various aspects of first order formalism [Kampf, Novotný, Trnka, 2006]

- equivalence with Proca and tensor formalisms
- saturation of LECs
- VVP correlator and vector formfactor [KNT, 2007]

Propagators and poles

Discussion for Proca fields (without group structure)

$$\mathcal{L} = -\frac{1}{4}\widehat{V}_{\mu\nu}\widehat{V}^{\mu\nu} + \frac{1}{2}M^2 V_\mu V^\mu + \mathcal{L}_{int}$$

The projectors

$$P^L_{\mu\nu} = \frac{p_\mu p_\nu}{p^2}, \qquad P^T_{\mu\nu} = g_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}.$$

Propagator

$$\Delta_{\mu\nu}(p) = -\frac{1}{p^2-M^2-\Sigma^T(p^2)}P^T_{\mu\nu} + \frac{1}{M^2+\Sigma^L(p^2)}P^L_{\mu\nu}.$$

with two possible poles belonging to P^L and P^T

$$M_V^2 - M^2 - \Sigma^T(M_V^2) = 0 \qquad \textbf{spin one states}$$

$$M_S^2 + \Sigma^L(M_S^2) = 0 \qquad \textbf{scalar modes}$$

Propagators and poles

Corresponding degrees of freedom: if $M_V^2 > 0,\ M_S^2 > 0$

$\Longrightarrow$ perturbative solution - spin one particle state (resonance)

$$\langle 0|V_\mu(0)|p,\lambda,V\rangle = |Z_V|^{1/2}\varepsilon_\mu^{(\lambda)}(p) \qquad \text{with} \quad Z_V = \frac{1}{1-\Sigma'^T(M_V^2)}$$

$\Longrightarrow$ possible additional pole that decouples in free field limit $(\Sigma^T(p^2) = 0)$

$\Longrightarrow$ scalar mode also frozen in free field limit

$$\langle 0|V_\mu(0)|p,S\rangle = \mathrm{i}p_\mu \frac{|Z_S|^{1/2}}{M_S} \qquad \text{where} \quad Z_S = \frac{1}{\Sigma'^L(M_S^2)}$$

Other kinetic and higher derivative terms make problems $\rightarrow$ they can appear by the renormalization procedure as counterterms

$$\mathcal{L}_{ct} = -\frac{\alpha}{4}\hat{V}^{\mu\nu}\hat{V}_{\mu\nu} - \frac{\beta}{2}(\partial_\mu V^\mu)^2 + \frac{\gamma}{2M^2}(\partial_\mu \hat{V}^{\mu\nu})(\partial^\rho \hat{V}_{\rho\nu}) + \frac{\delta}{2M^2}(\partial_\mu\partial_\rho V^\rho)(\partial^\mu\partial_\sigma V^\sigma)$$

Propagators and poles

Corresponding contributions to $\Sigma^T(p^2)$ and $\Sigma^L(p^2)$

$$\Sigma^T(p^2) = -\alpha p^2 + \gamma \frac{p^4}{M^2}, \qquad \Sigma^L(p^2) = -\beta p^2 + \delta \frac{p^4}{M^2}$$

For the masses and Z factors we get

$$M_V^2 = M^2 \left(1 + \frac{1 + \alpha - 2\gamma \mp \sqrt{(1+\alpha)^2 - 4\gamma}}{2\gamma} \right)$$

$$1 - \Sigma^{'T}(M_V^2) = \pm \sqrt{(1+\alpha)^2 - 4\gamma}$$

$$M_S^2 = M^2 \left(\frac{\beta \mp \sqrt{\beta^2 - 4\delta}}{2\delta} \right)$$

$$\Sigma^{'L}(M_S^2) = \mp \sqrt{\beta^2 - 4\delta}$$

- for $\alpha, \gamma \to 0$:

$$M_{V1}^2 = M^2(1 + \mathcal{O}(\alpha, \gamma)), \qquad M_{V2}^2 = \frac{M^2}{\gamma}(1 + \mathcal{O}(\alpha, \gamma)) + \ldots$$

- additional degree of freedom: for $\gamma > 0$ ghost, $\gamma < 0$ tachyon

Propagators and poles

Discussion of antisymmetric tensor fields (without group structure)

$$\mathcal{L} = -\frac{1}{2}(\partial_\mu R^{\mu\nu})(\partial^\rho R_{\rho\nu}) + \frac{1}{4}M^2 R_{\mu\nu}R^{\mu\nu} + \mathcal{L}_{int}.$$

The projectors

$$\Pi^T_{\mu\nu\alpha\beta} = \frac{1}{2}\left(P^T_{\mu\alpha}P^T_{\nu\beta} - P^T_{\nu\alpha}P^T_{\mu\beta}\right), \qquad \Pi^L_{\mu\nu\alpha\beta} = \frac{1}{2}\left(g_{\mu\alpha}g_{\nu\beta} - g_{\nu\alpha}g_{\mu\beta}\right) - \Pi^T_{\mu\nu\alpha\beta}$$

Propagator

$$\Delta_{\mu\nu\alpha\beta}(p) = -\frac{2}{p^2-M^2-\Sigma^L(p^2)}\Pi^L_{\mu\nu\alpha\beta} + \frac{2}{M^2+\Sigma^T(p^2)}\Pi^T_{\mu\nu\alpha\beta}$$

with two possible poles belonging to P^L and P^T

$M_V^2 - M^2 - \Sigma^L(M_V^2) = 0$ **spin one states**

$M_A^2 + \Sigma^T(M_A^2) = 0$ **spin one states with opposite parity**

Propagators and poles

Corresponding degrees of freedom: if $M_V^2 > 0$, $M_A^2 > 0$
$\Longrightarrow$ perturbative solution - spin one particle state (resonance)

$$\langle 0|R_{\mu\nu}(0)|p,\lambda,V\rangle = |Z_V|^{1/2} u_{\mu\nu}^{(\lambda)}(p) \qquad \text{with} \quad Z_V = \frac{1}{1-\Sigma'^L(M_V^2)}$$

where $u_{\mu\nu}^{(\lambda)}(p) = \frac{\mathrm{i}}{M_V}\left(p_\mu \varepsilon_\nu^{(\lambda)}(p) - p_\nu \varepsilon_\mu^{(\lambda)}(p)\right)$
$\Longrightarrow$ possible additional pole that decouples in free field limit $(\Sigma^L(p^2) = 0)$
$\Longrightarrow$ spin one state with opposite parity also frozen in free field limit

$$\langle 0|R_{\mu\nu}(0)|p,\lambda,A\rangle = |Z_A|^{1/2} w_{\mu\nu}^{(\lambda)}(p). \qquad \text{with} \quad Z_A = \frac{1}{\Sigma'^T(M_A^2)}$$

where $w_{\mu\nu}^{(\lambda)}(p) = \widetilde{u}_{\mu\nu}^{(\lambda)}(p) = \frac{1}{2}\varepsilon_{\mu\nu\alpha\beta} u^{(\lambda)\alpha\beta}(p)$

Propagators and poles

Lagrangian

$$\mathcal{L}_{ct} = \frac{\alpha-\beta}{2}\partial_\mu R^{\mu\nu}\partial^\rho R_{\rho\nu} - \frac{\beta}{4}\partial_\mu R^{\alpha\beta}\partial^\mu R_{\alpha\beta} + \frac{\gamma-\delta}{2M^2}\partial_\alpha\partial_\mu R^{\mu\nu}\partial^\alpha\partial^\rho R_{\rho\nu} + \frac{\delta}{2M^2}\partial_\rho\partial_\mu R^{\alpha\beta}\partial^\rho\partial^\mu R_{\alpha\beta}$$

Corresponding contributions to $\Sigma^T(p^2)$ and $\Sigma^L(p^2)$

$$\Sigma^L(p^2) = -\alpha p^2 + \gamma\frac{p^4}{M^2}, \qquad \Sigma^T(p^2) = -\beta p^2 + \delta\frac{p^4}{M^2}$$

The same masses and Z factors as in Proca field formalism

Propagators and poles

This is a well-known feature $\rightarrow$ massive Proca fields always make problems

Analogous situation is in antisymmetric tensor formalism!

First order formalism

- all types of possible additional degrees of freedom as in Proca and tensor formalisms
- splitting of masses, generation of new kinetic terms $\rightarrow$ doubling of degrees of freedom

The problems with ghosts do not depend on the formalism!

The origin of the problems

$\rightarrow$ non-conserving sources in Lagrangian $\Rightarrow$ new kinetic terms

$\rightarrow$ no symmetry to save this situation

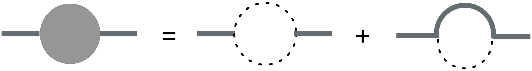
Ghosts in RχT

Interaction Lagrangian in antisymmetric tensor formalism

	$\mathcal{O}(p^6)$ odd parity with RR	coupling
1	$\epsilon_{\mu\nu\alpha\sigma}\langle\{R^{\mu\nu}, R^{\alpha\beta}\}D_\beta u^\sigma\rangle$	d_1
2	$\epsilon_{\mu\nu\alpha\beta}\langle\{R^{\mu\nu}, R^{\alpha\beta}\}\chi_-\rangle$	d_2
3	$\epsilon_{\rho\sigma\mu\lambda}\langle\{D_\nu R^{\mu\nu}, R^{\rho\sigma}\}u^\lambda\rangle$	d_3
4	$\epsilon_{\rho\sigma\mu\alpha}\langle\{D^\alpha R^{\mu\nu}, R^{\rho\sigma}\}u_\nu\rangle$	d_4

$\longrightarrow$ these terms make problems

One loop diagrams



Generation of new kinetic term as a counterterm

$$\mathcal{L}_{ct} = \alpha\langle D^\alpha R_{\mu\nu} D_\alpha R^{\mu\nu}\rangle$$

where $(\lambda_\infty = \frac{2\mu^{d-4}}{d-4} + \gamma_E - \ln 4\pi - 1)$

$$\alpha = \frac{5M^2\lambda_\infty}{48\pi^2F^2}\left[2d_1(d_1+d_3+d_4) - 3(d_3+d_4)(3d_3-d_4)\right].$$

Ghosts in RχT

Proca field formalism

- the chiral orders are shifted
  $\rightarrow$ nothing like this up to $\mathcal{O}(p^6)$
- we expect to appear this problem at $\mathcal{O}(p^8)$
- for example, if we take

$$\mathcal{L}_{V,int}^{(8)} = \sigma_V \epsilon_{\alpha\beta\mu\nu} \langle \{V^\alpha, \hat{V}^{\mu\nu}\} u^\beta \rangle$$

$\rightarrow$ additional degrees of freedom are generated

First order formalism

- more complicated structure of "ghost sector"

What to do with ghosts?

Solutions of the ghost problem:

- to throw them away (far from our energetic region) ?
- to postulate new symmetry ?
- to accept their existence as an artefact of RχT ?

Unfortunately, it is not easy to kill ghosts not only in fairy tales but also in Resonance chiral theory

What to do with ghosts?

Solutions of the ghost problem:

- to throw them away (far from our energetic region) ?
- to postulate new symmetry ?
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Unfortunately, it is not easy to kill ghosts not only in fairy tales but also in Resonance chiral theory

Thank you for attention!